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AUTHOR	Schrader, Clifford L.; Herron, J. Dudley
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ABSTRACT

This study was designed to investigate the role of information storage and processing in the cognitive process of synthesis. In particular the effect of the timing of the presentation of two subordinate informational concepts on the cognitive process of synthesis was examined. 88 high school students in four sections of an introductory chemistry course were used as the experimental population. The students were assigned to classes of approximately equal size by a computer on the basis of remaining space. The mean I.Q. scores for the class sections were compared as a partial check of the assumption that assignment was unbiased. The results of this investigation showed that: the proportion of learners who successfully acquired both subordinate informational concepts, A & B, did not differ significantly between treatment through written programmed learning material concerning on one day and material B on the next day versus treatment of written programmed material of A & B on the same day. This study suggests that the presentation of information at the same time facilitates the ability of the learner to synthesize. (Author/RG)

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Clifford L. Schrader
Dover High School
Dover, Ohio 44662

and

J. Dudley Herron
Purdue University
Lafayette, Indiana 47907

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SUMMARY

This study was designed to investigate the role of information storage and processing in the cognitive process of synthesis. In particular the effect of the timing of the presentation of two subordinate informational concepts on the cognitive process of synthesis was examined. The term subordinate information concept refers to that information which is generalized and learned as a concept, and which can then be combined with another independently learned informational concept to synthesize a new structure or concept not clearly there before. The cognitive process of synthesis has been defined in The Taxonomy of Educational Objectives; Handbook I: Cognitive Domain, (Bloom, 1956).

A hierarchy was proposed for each of eight topics in chemistry using the method suggested by Gagne. Each hierarchy consisted of two informational concepts, A and B, and a third concept, C, which could be obtained by synthesizing A and B.

The 88 high school students in four sections of an introductory chemistry course were used as the experimental population. The students were assigned to classes of approximately equal size by a computer on the basis of remaining space. The mean I.Q. scores for the class sections were compared as a partial check of the assumption that assignment was unbiased. The mean I.Q.'s of each class did not differ and homogeneity of variance was confirmed.

The process of synthesis was investigated by using eight units of chemistry subject matter. In each unit the learner was taught informational concepts A and B. A test was then given to determine if the learner had acquired both A and B, and if he could successfully synthesize them to produce C. In the first treatment group, X_1, the information was presented through written programmed learning material concerning A on one day, and similar material concerning B on the next day. One week later a written review of A was given, the following day a review of B was provided, and the next day the students were tested. In the second treatment group, X_2, the written programmed material concerning both A and B was given on the same day. One week later both A and B were reviewed and the following day the students were tested. The tests were composed of free response items which required the student to indicate the process used in answering the question.

In three of the eight units the proportion of students who were successful in synthesizing A and B in treatment group X_2 was higher than the proportion of successful students in treatment group X_1 at the .05 level of confidence. This supports Ausubel's theory that information is processed during storage and suggests that to maximize

the ability of learners to synthesize, the subordinate informational concepts should be presented together.

The proportion of learners who successfully acquired both subordinate informational concepts, A and B, did not differ significantly between treatment X_1 and X_2 for any of the eight units. This indicates that the method of teaching the learners A and B was not biased by one of the treatment procedures.

In summary, the results of this investigation show that:

1) For three of the eight units included in the study, students who were taught subordinate concepts A and B on the same day were better able to synthesize the data to produce the superordinate concept, C, than were students who were taught the subordinate concepts on separate days.

2) The proportion of students in the two treatment groups who learned the subordinate concepts, A and B, did not differ.

3) Seven of the eight hierarchies showing the relationship between the subordinate concepts, A and B, and the superordinate concept, C, were shown to be valid; i.e., the consistency ratio exceeded 0.90. The consistency ratio for the eighth hierarchy was 0.795.

4) It was found that testing for retention of subordinate concepts, A and B, provided a cueing effect which resulted in improved performance on items designed to measure synthesis of these data to produce the superordinate concept, C.

5) A moderate correlation (0.36) was found between I.Q. and performance on the synthesis items.

The cognitive ability described as synthesis may be closer to the goals of science instruction than any other. This study suggests that the presentation of information at the same time facilitates the ability of the learner to synthesize. The question of whether the ability of individual learners to synthesize can be increased is unanswered by this study and merits further investigation.

INTRODUCTION

Man's quest to obtain knowledge of nature is the essence of science. The role of education in science should include more than the assimilation of the current body of facts. Scientists and educators need to be concerned with the production of new information. Important discoveries frequently require the synthesis of existing information; therefore, a careful study of the effect of the timing of the presentation of information on the process of synthesis is warrented.

Synthesis

Synthesis, as used in this study, is defined in The Taxonomy of Educational Objectives, Handbook I: Cognitive Domain. (Bloom, 1956.) A concise definition of synthesis is presented as follows:

> " [Synthesis is] the putting together of elements and parts so as to form a whole. This involves the process of working with pieces, parts, elements, etc., and arranging and combining them in such a way as to constitute a pattern or structure not clearly there before." (Bloom, p. 206)

This definition of synthesis encompasses a broad spectrum of abilities. The synthesis required of students in this study is limited and may best be described by Bloom's category, 5.30, Derivation of a Set of Abstract Relations. In describing this type of synthesis, Bloom says:

> The distinguishing feature of this sub-category is . . . the attempt to derive abstract relations from a detailed analysis. The relations themselves are not explicit from the start; they must be discovered or deduced. (Bloom, p. 164)
>
> There seem to be two somewhat different kinds of tasks here: (1) those in which the student begins with concrete data or phenomena and which he must somehow either classify or explain; (2) those in which the student begins with some basic propositions or other symbolic representations and from which he must deduce other propositions or relations. (Bloom, p. 171. Emphasis added.)

It is this second situation that best describes the synthesis that was required of students in this study. Any inferences based on this study are necessarily limited to this type of student performance.

The effect of the timing of the presentation of two subordinate informational concepts in the process of synthesis can be investigated by using the approach of Gagne (1962) to construct hierarchies which assess the extent of the information stored. It is necessary to

measure both the relevant subordinate capabilities in a cognitive task and the task itself.

The process of synthesis can be investigated by presenting two separate informational concepts A and B which can be synthesized to produce a new informational concept C not there before. The term subordinate informational concept refers to that information which is generalized and learned as a concept, and which can be combined with another independently learned informational concept to synthesize a new structure or concept not clearly there before. The synthesis process can be represented by a Gagne-type hierarchy as shown:

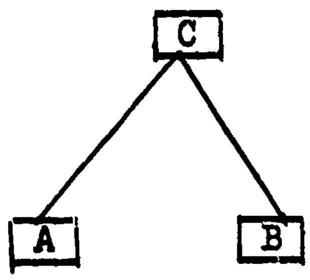

Figure 1. A Simple Hierarchy

Purpose of the Research

The primary goal of this study is to investigate the effect of the timing of the presentation of two subordinate informational concepts (subsequently referrred to as A and B) on the synthesis of a higher order concept (subsequently referred to as C). Ausubel (1963) proposed that information which is "meaningful" is associated with other information in the cognitive structure of the learner. Rotely learned material, by contrast, is not integrated into the cognitive structure. If this "meaningful" information is to be related, it will be related during storage. He suggested that one condition under which separate items of information will be related is when they are presented or learned at the same time. Underwood (1969) has identified the "temporal factor", i.e., the sequencing in time and the time interval, as a potent factor in memory. This suggests that information which is learned together tends to be remembered together, thus such information may be more easily related.

Specifically the purpose of this study is to investigate the hypothesis that students who have been presented A and B at the same time will be more successful in synthesizing them to produce C than students who have been presented A and B at different times. The retrieval of A and B will be measured directly, and the performance on a task C which requires the synthesis of A and B will be measured.

A secondary purpose is to establish the validity of the proposed hierarchies which are being used in the research. Empirical data will clarify the theoretical understanding of these processes and will suggest appropriate curriculum revisions and improved teaching strategies.

Outline of the Research

The students in the chemistry classes of Dover High School, Dover, Ohio, in the 1970-71 academic year were used as the research population. The treatments were administered to individuals in four classes and data were pooled for classes with the same method of presentation. The data from the research carried out was analyzed to examine the following five ideas:

1. Direct Comparison of Success in Synthesizing C Between Groups

The proportion of students successful in synthesizing C when A and B were presented together is compared to the proportion of students successful in synthesizing C when A and B are presented at different times.

2. Validation of the Proposed Hierarchies

The approach of Gagne (1962) is used to determine whether relationships within the hierarchy are validated by the observed responses. If the hierarchy is valid, only those learners who successfully respond to both A and B will succeed in synthesizing C.

3. Information Storage

A and B are separate informational concepts and should be as easily recalled when presented together as when presented separately. The proportion of students responding successfully to both A and B, when A and B are presented together is compared to the proportion successfully responding to both A and B, when A and B are presented separately.

4. Cueing Effects of Testing the Entire Hierarchy

When the students are tested to determine if they have acquired A and B and can successfully synthesize A and B to produce C, the testing for A and B may provide a cue to the students that A and B are to be combined. This possible cueing effect is examined by first determining if the students can successfully synthesize C. After this test is completed, the students are evaluated to determine if they can successfully produce A and B, and then synthesize A and B to produce C.

5. Correlation of Ability to Synthesize and I.Q.

The ability to synthesize may be related to a standardized cognitive measure. The correlation between I.Q. and ability to synthesize was determined by comparing the total score on all synthesis items for all units to the I.Q. score for each individual. I.Q. is a measure of general mental ability and should be significantly correlated with the cognitive ability of synthesis.

Significance of the Research

This study is an empirical test of basic cognitive learning theory. The implications of Bloom's Taxonomy overlap with Ausubel's theory of information acquisition during meaningful verbal learning and the hierarchical arrangement of the cognitive processes suggested by Gagne. If the existence of a given hirarchy which involves the process of synthesis is established, one can still choose to present the subordinate concepts at the same time or separated in time. Will presenting A and B at the same time facilitate synthesis? The answer to this question would aid in formulating a model for the interaction of information storage with cognitive structure during learning. The empirical data will also suggest appropriate teaching strategies.

The cognitive process of synthesis has been subjected to very little research, yet this process is vital to the formation of new knowledge. Although this study is being done using chemistry as subject matter, the synthesis process as described in the Taxonomy is thought to be a general process independent of subject matter content. Chemistry is a representative area of knowledge, and perhaps somewhat easier to experiment with since the students are generally unfamiliar with the material presented. While the results of this study can not be generalized to other subject matter areas, it is quite possible that similar results would be obtained in other areas.

LITERATURE REVIEW

The publication of The Taxonomy of Educational Objectives, Handbook I: Cognitive Domain, edited by Bloom (1956), generated interest in the role of information processing in the higher cognitive processes. The Taxonomy is based on the assumption that the arrangement of the categories - knowledge, comprehension, application, analysis, synthesis, and evaluation - is hierarchical, in that order, according to complexity of process. The hierarchy of categories is assumed to be cumulative; i.e., any given category consists of the processes stipulated by lower-level categories, and in addition, a process which is unique to it from the standpoint of lower-order categories.

Empirical Studies of the Taxonomy

There have been seven empirical studies which explored the validity of the Taxonomy. Anderson (1964), Herron (1965), Schaff (1970), and Even (1970) investigated the relationship of the Taxonomy to particular chemistry curricula. Anderson (1964) investigated the first four levels of the Taxonomy, and found that low ability Chem Study students were superior in analysis to low ability students in traditional chemistry, but information was not held constant for both groups. Herron (1965) attempted to evaluate all six cognitive levels and experienced difficulty in constructing an adequate test. The limited amount of testing time available restricted the number of test items that could be used, and therefore, not enough information could be obtained with respect to the interrelationships implied in the Taxonomy.

Schaff (1970) concentrated only on evaluation, the highest cognitive level of the Taxonomy. The results indicated that the students in Chem Study classes were superior to the students in traditional chemistry classes in ability to evaluate, even when knowledge was held constant. In this study the knowledge measured was shown to be related to the cognitive process of evaluation. However, the differences found between the groups were mainly due to lower scores on the evaluation post-test by the control group, and not higher scores by the evaluation post-test treatment group.

Even (1970) investigated the correlation between course grade in chemistry and each of the first four levels of the Taxonomy. The correlations for knowledge, comprehension, and application were .48, .44, and .49 respectively. The highest level of the Taxonomy used, analysis, had the lowest correlation with course grade (.32). It would be interesting to determine if the correlation between course grade and higher cognitive levels is smaller still.

McFall (1964) grouped the levels of the Taxonomy into two areas. One area was the ability to recall knowledge, and the other area was the ability to handle concepts, analyze principles, render judgments, and evaluate material. He constructed a test designed to evaluate: (a) the ability to recall specific facts, and (b) to deal with the higher cognitive tasks. The correlations of subtest (a) with the Stanford Achievement Test and with course grade were significantly higher than the correlations of (b) with the Stanford Achievement Test and with course grade. This supports the contention that a significantly lower correlation exists between a test of the higher cognitive processes and current methods of evaluating achievement than the correlation between recall of knowledge and current methods of evaluating achievement.

A study by Stoker and Kropp (1964) was designed to test the hierarchical nature of the Taxonomy. Two tests were constructed which consisted of a reading passage dealing with content unfamiliar to the learners (atomic structure and the periodic table) and a test for each reading passage. Five chemistry teachers who were familiar with the Taxonomy independently classified the test items according to the level of the Taxonomy. The raters did tend to categorize items in congruence with the behaviors the items were intended to invoke. Herron (1965) also found satisfactory interrater agreement in the classification of the items designed to evaluate all levels of the Taxonomy.

The tests constructed by Stoker and Kropp (1964) were administered to over 1000 high school students and analysis of the data indicated that the Taxonomy was hierarchical. Factor analysis of the data, however, failed to support the hypothesized structure. Smith (1968) subjected Stoker and Kropp's data to further analysis in the manner described by McQuitty (1966) as hierarchical classification by reciprocal pairs. He found that of the six major classes of the Taxonomy, only knowledge and evaluation behave in a manner inconsistent with the theoretical formulation.

These studies suggest that the Taxonomy is a useful model, and there is evidence to support the hypothesized hierarchical structure of the Taxonomy. To investigate the Taxonomy as a whole is a difficult task because a large number of test items is required. It is therefore appropriate to investigate the hierarchical structure of a part of the Taxonomy.

Hierarchies and Mental Tasks

In a study of programmed-learning materials in mathematics, Gagne and Brown (1961) obtained results which suggested that what is learned relevant to a situation is more important in transfer for problem-solving than how it is learned. It seemed that differences in individual performances might be attributable to certain skills which were needed in order to do what the program demanded. The follow up study by Gagne

(1962) was designed to identify these subordinate skills by successively asking the question, "what would the individual have to know how to do in order to learn this new capability simply by being given verbal instructions?" The studies of Gagne and Staff (1962), Drumm (1965), Wiegand (1969), Gagne and Bassler (1963), Harke (1969), Okey and Gagne (1970), and Bredemeier (1970) gave additional evidence that learning hierarchies can be validated.

These studies suggest the existence of hierarchies in learning. If hierarchies do exist, additional questions concerning the hierarchical nature of learning require examination. The effects of the timing of the presentation of the subordinate concepts on learning and the learner's ability to synthesize these subordinate concepts has not been investigated.

Some Aspects of Ausubel's Learning Theory

Ausubel (1963) proposed a theory of information acquisition which differentiates between rotely learned material and meaningful verbal learning. He asserts that the rotely learned information and meaningful verbal learning are organized quite differently in cognitive structure and hence conform to quite different principales of learning and forgetting. Meaningfully learned materials have been related to existing concepts in cognitive structure in ways making possible the understanding of various kinds of significant relationships. If two materials have been presented together they could become related during learning and form new cognitive structure. Rotely learned materials, however, are discrete and isolated entities which are only relatable to cognitive structure in an arbitrary, verbatim fashion; and, because they are not anchored to existing ideational systems, rotely learned materials are much more vulnerable to forgetting.

The model of cognitive organization proposed for the learning and retention of meaningful materials assumes the existence of a cognitive structure that is hierarchically organized in terms of highly inclusive conceptual traces, under which are subsumed traces of less inclusive subconcepts, as well as traces of specific informational material. The major organizational principle is that of progressive differentiation of trace systems of a given sphere of knowledge from regions of greater to lesser inclusiveness, each linked to the next higher step in the hierarchy through a process of subsumption.

Murray (1963) tested a concept formation model and found that information processing ability (analytical ability), as measured by tests utilizing items of the Taxonomy of level two or higher, did not appear related to a student's success in solving new problems, when information store was held constant, but did have a marked effect on the rate of information acquisition. The tentative conclusion, on the basis of

Murray's study, was that information processing ability affects learning primarily at the input stage when the information is stored, and not when the information is retrieved from storage. This agrees with Ausubel's theory that highly developed cognitive structure aids the acquisition of knowledge. The very low reliabilities of the tests of analytical ability (less than .50) obscure the results, and the correlations with other tests of analytical ability were lower still (the correlations ranged from .07 to .23).

Taylor (1966) studied concept formation as a function of information input in college chemistry. The treatment group was given high density information instruction through the use of additional problems, exercises and other activities designed to expose them to more information about a concept. The results suggested that a high density of information input increased the amount of information acquired in the treatment group, as compared to the control group. In both the experimental and the control groups, students high in analytic ability acquired more information than students with low analytic ability. This is in agreement with Murray's data and suggests that analytic ability is a measure of the cognitive structure which serves to process the information during input.

Ring (1970) investigated the effects of cognitive structure on achievement in college chemistry by measuring the cognitive structure and the fact orientation of the students. Questions were posed which required either a factual answer or the existence of subsumers in the cognitive structure of the student. The results indicated that the existence of a large amount of relevant subsumers, or appropriate cognitive structure, facilitates the learning of new material, and students who possess a large amount of facts without sumsumers achieve at a low level.

The studies cited support Ausubel's theory that if information is to be learned in a meaningful way, and therefore retained, the existence of appropriate cognitive structure is necessary. An inherent difficulty with Ausubel's theory is that the existence of cognitive structure or the presence of subsumers is based on indirect evidence. The Cognitive Structure Exam has 14 items which purport to measure subsumers and 12 items which are designed to measure facts. The validity and reliability of this test need to be better established.

The studies cited suggest that cognitive structure as postulated by Ausubel does exist, and does influence the acquisition of information. The evidence is based on tests which select learners on the basis of some higher cognitive ability. These selected learners have superior ability to acquire, retain and retrieve information. These studies have not investigated the effect of the timing of the presentation of the information on the learning of this information. Information which is learned could be related by the existing cognitive structure or relationships could be perceived during the learning process. The perception of a relationship between two separate pieces of information is called synthesis.

The Synthesis Level and Cognitive Structure

Three empirical studies have been directed toward the synthesis process. Wasik (1967) attempted to validate the Taxonomy processes of synthesis and evaluation with a reading passage and a test using social studies content and science content. The construct validity was determined by relating the results of the synthesis test to the results on Guilford's test of divergent production. Wasik felt science and social studies synthesis subtests were valid measures of the synthesis process, but subsequent analysis indicated the two subtests were measuring different aspects of the synthesis process. This agrees with the results of Murray (1963), Taylor (1966), and Ring (1970) who also found that content-process interaction occurs.

Based on the assumptions of the Taxonomy and its definitions of the cognitive processes, Smith (1970) found a significant relationship between intelligence and the knowledge, comprehension, application, and analysis categories. The contribution of intelligence was uniform and significant for each of the four levels. Creativity, however, did not make a significant contribution to variation beyond intelligence. Both intelligence and creativity made significant, independent, and overall contributions to variation on the synthesis and evaluation levels.

Smith and Mangum (1970) made a comparison of the performance of students who can recall a principle after a period of years, as opposed to those who can only recognize the principle, in terms of their ability to profit from a communication. The communication consisted of a description of an experiment, the resulting data, the principle to be derived from the data, and definitions of key concepts. The test items were constructed according to the Taxonomy, and an attempt was made to hold content constant and systematically vary the cognitive process. On the synthesis item, the students appeared to answer the question by the process of eliminating the alternatives, rather than by formulating a hypothesis or an experiment. The recall group was found to be significantly better than the recognition group on all items at the .01 level.

From these studies it is clear that not enough is known about the synthesis process. The synthesis process has been related to divergent production, I.Q. and creativity through correlational studies. Smith and Mangum (1970) attempted to select students who possessed higher cognitive skills on the basis of their ability to recall a principle in science a long period of time after acquiring the principle. These students were found to be significantly better at the process of synthesis.

Still, these studies did not assess the existence of relevant subordinate concepts by holding knowledge constant. In addition, the timing of the presentation of the subordinate concepts has not been investigated, and it may be an important factor - especially in the process of synthesis.

Purpose of the Research

The studies cited provide evidence that Bloom's *Taxonomy*, Gagne's hierarchies, and Ausubel's learning theory have some validity. The cognitive process of synthesis involves all three of these ideas and the interrelationship of information storage and processing, hierarchies, and synthesis require investigation. Only the studies of Wasik (1967), Smith (1970), and Smith and Mangum (1970) have dealt with the process of synthesis, and the investigation involved synthesis in a peripheral way.

This study ascertains the existence of the relevant knowledge and concepts in the hierarchy, their role in the process of synthesis and the effects of information storage on the ability of the learners to synthesize. It makes use of and provides information about Ausubel's theory, Gagne's hierarchies, and the synthesis level of Bloom's *Taxonomy*.

EXPERIMENTAL PROCEDURE

Sample

The major focus of this research was a comparison of the proportion of learners successful in achieving the synthesis of informational concepts A and B between treatments. In treatment X_1, A was presented on one day and B was presented the following day, while in treatment X_2, A and B were both presented on the same day. The individual students in the chemistry classes of Dover High School were used as a population for the research. These classes contained college preparatory students in an introductory chemistry course during the 1970-71 school year. Each class met three days each week for a 44 minute period and two days each week for an 88 minute period.

The text used was Modern Chemistry (Holt, 1963) and the treatment units were selected from the material in the text. The material used in the units is common to most high school chemistry texts. These units are contained in the appendix.

The enrollment of approximately 88 students was divided into four nearly equal sections of 26, 22, 21, and 19 students. The enrollment fluctuated slightly throughout the year since four students withdrew from chemistry and one new student enrolled in January. The students were assigned to the classes by a computer on the basis of remaining space in classes. An investigation by Hagerman (1966) indicated that this was likely to be an unbiased assignment. A test of homogeneity of variance and equality of means of I.Q. scores was done to check this assumption. I.Q. was chosen because Smith (1970) found that I.Q. made a significant contribution to variation for synthesis items. The mean I.Q. for each section is given in Table 1.

Table 1. Mean I.Q. Score for Each Section of Chemistry

	Section A	Section B	Section C	Section D
Mean I.Q.	113.2	116.2	119.3	114.7

A one way analysis of variance as described in Winer (1962) was done to determine if these means differed significantly and the results are given in Table 2. There was no evidence that the students who withdrew or entered were different from the rest of the students in the classes with respect to I.Q. The average I.Q. for all students was 116,

and the average I.Q. for those students who entered or withdrew was 115. The I.Q. scores were analyzed for only those students who were present for at least four of the treatment units, therefore the number of degrees of freedom within groups is 82 and not 85.

Table 2. Analysis of Variance of I.Q. Scores

Source of Variation	Sum of Squares	Degrees of Freedom	Mean Square	F
Between Groups	438.15	3	146.05	1.64
Within Groups	7295.16	82	88.97	
Total	7733.31	85		

Since $F_{.95}(3, 82) = 2.72$ and the value obtained for $F = 1.64$, there is no significant difference between the class means at the .05 level. This indicates that there is no evidence of bias with respect to I.Q. in the assignment of students to classes by the computer.

The Hartley $F_{max.}$ test of homogeneity of variance as described in Winer (1962) was done and the results are given in Table 3. Since $F_{max\ .95}(4, 24) = 2.9$, and the value obtained for $F_{max.} = 1.95$, homogeneity of variance is supported.

Table 3. Homogeneity of Variance of I.Q. Scores

	Section A	Section B	Section C	Section D
Sum of Squares	1688.00	1861.27	2522.20	1223.68
Degrees of Freedom	25	22	20	19
Variance	70.33	88.63	132.75	67.98
$F_{max.}$	1.95			

In addition, the observations of the teacher indicated that the class sections did not differ significantly with respect to grades, skill in laboratory, quality of class discussion, and attitude toward chemistry. This increases one's confidence that the assignment of students to classes was unbiased.

Treatments

The treatments consisted of hierarchies of chemistry subject matter designed to teach the learners two separate informational concepts A and B. Concepts A and B are relatable and can be synthesized to produce a new concept C. The concepts are assumed to be hierarchial in nature as represented in Figure 1 on page 4. The purpose of the treatment is to teach A and B effectively to all learners in a controlled and unbiased way. One treatment group (X_1) learned A and B separately while the other treatment group (X_2) learned A and B together.

Time is one of the factors which has been identified by Underwood (1969) as influencing the learning, retention, and retrieval of information. The sequencing in time and the time interval, called the "temporal factor", has been shown to be influential in determining which information will be associated with other information in empirical research by Van Mondfrans and Travers (1965), Bugelski and Rickwood (1963), and Murdock (1960). These studies suggest that information which is learned at the same time tends to be recalled at the same time, and thus such information can be related more easily. It is felt that the separation of presentation of A and B by one day would effectively ensure that they are learned separately.

A pilot study indicated that the presentation of the information by giving the learners a page of written material to read was not sufficiently effective in teaching A and B. Since the primary purpose of this research is to investigate the process of synthesis, it is desirable to have a very high proportion of learners (ideally 100%) acquire both A and B. Then one can compare the number of learners successful in synthesizing C between treatment groups X_1 (separate presentation of A and B) and treatment group X_2 (presentation of A and B at the same time).

To increase the proportion of students who successfully acquired both A and B, the presentation of A and B was expanded to a written programmed learning format. The materials used are in the appendix. The learners, after reading the expository material, were required to respond to questions designed to focus their attention on the pertinent aspects of the written material and were given answers to these questions to provide immediate feedback. To further increase the proportion of learners that acquired A and B, the original expository material was given as a review exercise after an interval of one week. Since the review materials contain nothing new but consist of the original expository material with the questions deleted, these materials are not in the appendix.

Design

In treatment X_1 the information concerning concept A was presented on Monday through written programmed learning material, and the information concerning concept B was presented Tuesday through written programmed learning material. The following Monday only the expository material containing A was given as review, on the following Tuesday only

the expository material containing B was given, and on Wednesday the students were given the criterion test.

For treatment X_2, A and B were both presented on Tuesday through written programmed learning material. The following Tuesday the expository material was given as review and on Wednesday the students were given the criterion test. The lotal learning time and testing time available to both treatments was the same.

To avoid the appearance of an experiment, the material presented was used in discussions and experiments after the criterion test was given. The students accepted the material as a natural part of the chemistry course. In the beginning of the year the teacher discussed his philosophy of education. This included an expressed belief that students could learn by listening to lectures, by participating in class discussions, through laboratory experiments, and by reading written material. He stated that students ought to gain experience in learning in all four ways, and each time the treatment material was handed out, students were reminded of this statement of philosophy. It is felt that this enabled the students to accept the experimental setting as a part of the classroom routine.

Many students had difficulty in synthesizing A and B and became discouraged, although every student was successful at least once. The mean score on synthesis items was 4.7 correct responses per student. Even so, many students reacted negatively to the experimental materials, especially after the fifth treatment. Since these exercises were counted as a part of their grade, it is felt that they performed up to their capabilities on each treatment unit.

The results for all students within each treatment were pooled. Pooling the results amounts to combining the class results of similar treatments. To eliminate bias, each class should be combined with each other class for each treatment. There are six permutations and these are shown in Table 4 under the Units 1 through 6. Also included in Table 4 is the procedure used in Units 7 and 8, which are repetitions of the method of assigning treatments for Units 2 and 1 respectively. Although only the first six permutations are unique, units 7 and 8 were also presented to the learners as shown in Table 4 to provide additional data.

Table 4. Method of Assigning Groups to Treatment

Unit	1	2	3	4	5	6	7	8
Section A	X_1	X_2	X_1	X_1	X_2	X_2	X_2	X_1
Section B	X_2	X_1	X_1	X_2	X_1	X_2	X_1	X_2
Section C	X_2	X_1	X_2	X_1	X_2	X_1	X_1	X_2
Section D	X_1	X_2	X_2	X_2	X_1	X_1	X_2	X_1

Measuring Instruments

The previous investigations of the higher cognitive processes did not assess the relevant information in the hierarchy leading up to the cognitive process in the manner described by Gagne (1969). To strengthen the research design a more complete evaluation was done. The criterion test used consisted of free response items prepared by the researcher that assess the hierarchy consisting of the synthesis item C and the two subordinate concepts A and B. To disguise the nature of the research and prevent the structure of the test from giving students clues, some additional lower level items were also included. The content validity of the test items was determined by using a panel of subject matter experts who also had extensive experience with the Taxonomy.

Kropp, Stoker, and Bashaw (1966) discussed some of the problems associated with choosing the response measure which will be regarded as indicative of the presence or absence of cognitive behaviors.

> The choice of the proper response measure is crucial if one wishes to obtain the best evidence on which to validate any behavioral measure. In the case of the Taxonomy, two possible response measures come immediately to mind. One is whether the desired intellectual process is used by the student. The other is whether the student gives a correct response to an item. The former will be referred to as the process response; the latter, the product response.
>
> Using a process response measure requires detecting whether the student used the intended process when reaching his solution to the item. Identifying the process would require that information about the process be collected. One method by which this might be done is to collect verbalizations from the student while he is solving the problem.
>
> Detecting the presence or absence of the desired process from the solution which the student verbalized is a difficult task that requires well-trained judges who manifest high inter-rater reliability. (Kropp, Stoker, and Bashaw, 1966, p. 71-72)

Since it was desirable to have evidence that the students were engaged in the synthesis process, a specific question was asked and the students were required to give their answer and also explain why they gave the answer. The written explanations correspond to the collection of verbalizations referred to by Kropp, Stoker, and Bashaw (1966).

Free response items eliminated the need for guessing corrections cited by Aiken (1965), Cureton (1966), Ebel (1968), Edgington (1965), and Little (1966). Free response items also eliminated the problem found by Smith and Mangum (1970), that students tended to respond to

multiple choice synthesis items by eliminating choices rather than by formulating hypotheses.

The criterion for scoring the tests was established prior to administering the tests. The tests were than graded by three qualified chemistry teachers and the interjudge reliabilities were computed using the procedure described in Winer (1962). The results are given in Table 5. The reliability was computed separately for each section of students, the total reliability for that unit was calculated and the over-all reliability of all items was found.

Table 5. Interjudge Reliabilities for the Criterion Tests

Unit	Section A	Section B	Section C	Section D	Total
1	.834	.921	.859	.911	.889
2	.580	.921	.968	.612	.807
3	.932	.929	.936	.898	.930
4	.743	.804	.920	.424	.767
5	.992	.989	.988	.995	.991
6	.893	.861	.892	.922	.893
7	.982	.974	.991	.959	.978
8	.910	.630	.992	.955	.937
Over-all					.933

The reliabilities are quite high except for section A in unit 2 and section D in unit 4, but the total reliabilities for these two units are respectable. The high reliability of the tests used may be attributed to two factors. First, the judges were in close agreement about what constituted a correct response. Second, the questions made clear what sort of response was desired, and it was not difficult to ascertain which student responses were adequate.

Validation of Hierarchies

Validation of the hierarchies is carried out using the method described in the American Association for the Advancement of Science report. (American Association for the Advancement of Science, 1968.)

If the hierarchies are consistent with the proposed hierarchy, only those learners successful in acquiring both A and B will succeed in synthesizing C. The consistency ratio was calculated by dividing the number of consistent hierarchies by the total number of learners. An inconsistent hierarchy is one in which the learner fails to acquire either A or B or both but succeeds in synthesizing C. For the hierarchy in Figure 1 the possible responses are given in Figure 2.

+	0	0	0	0	+	+	+
+ +	+ +	+ 0	0 +	0 0	0 +	+ 0	0 0
(a)	(b)	(c)	(d)	(e)	(f)	(g)	(h)

Figure 2. Possible Responses to the Hierarchy Given in Figure 1

A + indicates success and a 0 indicates failure. The first five patterns a, b, c, d, and e are consistent and the last three (f, g, and h) are inconsistent. The consistency ratio is equal to the sum of the consistent hierarchies divided by the sum of all possible hierarchies.

$$\text{Consistency Ratio} = \frac{a + b + c + d + e}{a + b + c + d + e + f + g + h}$$

The AAAS Science - A Process Approach evaluation report suggested a consistency ratio equal to or greater than .90 for hierarchy validation (American Association for the Advancement of Science, 1968). The consistency ratio satisfied this requirement for all units except unit 8. There were other problems associated with unit 8 and the written material in unit 8 was felt to be inadequate to teach the concepts involved. The results summarized in Table 6 indicate that the proposed hierarchies were valid and provided additional evidence to support Gagne's model of hierarchies.

Table 6. Consistency Ratio for the Proposed Hierarchies

Unit	Number of Consistent Hierarchies	Total of All Possible Hierarchies	Consistency Ratio
1	87	88	.989
2	81	88	.920
3	85	85	1.000
4	85	85	1.000
5	85	86	.988
6	81	85	.953
7	81	82	.988
8	58	73	.795

Proportion of Eligible Learners

If the hierarchies were valid, and there was evidence that they were, only those learners who had acquired both A and B would have been successful in synthesizing C. Students who acquired both A and B were designated as "eligible learners". Since the primary aim of the research was to evaluate the effect of information storage on the process of synthesis, it was desirable to maximize the proportion of eligible learners. The proportion of eligible learners was calculated and is given in Table 7.

Except for units 2, 5, and 8 the proportions are quite good. The low proportion in unit 2 was probably due to the difficulty of the material and the inadequacy of the written material. Atomic structure was the topic in unit 2. The written information A included the concept that as the atomic number is increased the number of shells in the atom increases periodically. Since these shells are assumed to be concentric in our simplified model of the atom, increasing the number of shells increases the atomic radius. The written information B included the concept that as the atomic number is increased the attracting power of the nucleus becomes larger, which results in a smaller atom. Many students asked the teacher which statement was correct and were informed that no discussion was permitted since the stated objective of these units was to require students to learn by reading. As a result of the ensuing frustration many students became "fixated" on either A or B. They chose either A or B as the correct concept and ignored the other concept. The quality of the exposition needs to be improved despite the fact that unit 2 was used in a pilot study and revised extensively according to the feedback received.

Table 7. Proportion of Eligible Learners

Unit	Number of Eligible Learners	N	Proportion
1	86	88	.977
2	42	82	.477
3	51	85	.600
4	74	85	.871
5	31	86	.361
6	57	85	.671
7	60	82	.732
8	19	73	.260

The students had particular difficulty with unit 5, which required an explicit quantitative comprehension of an abstract concept (the mole), and the concomitant calculations. This material will be revised to provide more exercises which require responses by the student.

Unit 8 was equilibrium and exposition through written material did not seem to be an appropriate method for teaching these concepts. If this unit can not be revised successfully it will be eliminated from further research efforts.

EXPERIMENTAL RESULTS

The Effect of Treatment on the Number of Eligible Learners

Before comparing the success of the eligible learners in synthesizing C, it is necessary to investigate the effect of treatment on the acquisition of A and B to determine if the proportion of eligible learners is different between treatments. The proportion of eligible learners in treatment X_1 and the proportion of eligible learners in treatment X_2 were compared to determine if they differed significantly by using the procedure described in Edwards (1968). Ausubel's theory predicts that those learners who were presented A and B together would store them more effectively than the learners who were presented A and B separately. This was not verified by the data given in Table 8, which shows no significant difference for all units. It is quite possible that the informational concepts A and B did not require extensive ideational anchorage to be successfully acquired, or that the required cognitive network was present to approximately the same extent in all learners. It is perhaps more likely that the material used was not excessively complex, and the programmed material allowed both treatment groups to develop the relevant cognitive structure to the same extent. In units 2, 3, and 7 the proportion successful was higher for X_2, in units 4, 5, 6, and 8 the proportion was higher for X_1, while the proportions were nearly identical for unit 1. None of the differences were significant at the .05 level and it is assumed that all differences are due to chance.

Proportion of Eligible Learners Successfully Synthesizing C

The proportion of eligible learners successful in synthesizing C was determined for each unit to find if there was a significant difference, using the procedure described in Edwards (1968). Ausubel's theory suggests that the ideational anchorage will be more extensively developed during the storing process when A and B are presented together. This cognitive network would then facilitate the processing of the information and a higher proportion of the group undergoing treatment X_2 should succeed in synthesizing C.

The proportion of eligible learners successful in synthesizing was higher for treatment X_2 than for treatment X_1, for units 1, 3, and 6. These differences were significant at the .05 level for units 1 and 6 and at the .01 level for unit 3. The results for the pooled data are summarized in Table 9.

In unit 1 the class sections B and C were assigned the more successful treatment, in unit 3 the class sections C and D were the more successful, and in unit 6 the class sections A and B were the more successful. This shows that the more successful treatment group did not always contain a particular class section. This increases one's confidence that the differences found were due to the treatment and not to some undetermined bias among class sections.

Table 8. Test of Significance Between Proportions of Eligible Learners Who Correctly Acquired Both A and B by Treatment Groups

Unit	Treatment	Number of Eligible Learners	N	Proportion of Eligible Learners	Z
1	X_1	44	45	.9777	.0028
	X_2	42	43	.9767	
2	X_1	17	44	.387	1.49
	X_2	25	46	.544	
3	X_1	25	47	.535	1.20
	X_2	26	38	.644	
4	X_1	42	45	.934	1.223
	X_2	32	40	.801	
5	X_1	18	40	.450	1.54
	X_2	13	46	.283	
6	X_1	26	37	.703	.521
	X_2	31	48	.646	
7	X_1	29	42	.691	.76
	X_2	31	40	.775	
8	X_1	12	40	.300	.813
	X_2	7	34	.206	

Table 9. Test of Significance Between Proportions of Eligible Learners Successful in Synthesis

Unit	Treatment	Number of Eligible Learners Successful in Synthesis	Total No. of Eligible Learners	Proportion of Eligible Learners Successful in Synthesis	Z
1	X_1	21	44	.477	1.76*
	X_2	28	42	.666	
2	X_1	8	17	.471	.317
	X_2	13	25	.521	
3	X_1	6	25	.240	2.95**
	X_2	17	26	.654	
4	X_1	38	41	.927	.349
	X_2	31	32	.968	
5	X_1	3	18	.166	-.069
	X_2	2	13	.154	
6	X_1	3	26	.115	1.80*
	X_2	11	31	.355	
7	X_1	12	29	.414	.588
	X_2	15	31	.484	
8	X_1	4	12	.333	1.62
	X_2	5	7	.714	

* Significant at the .05 level.

** Significant at the .01 level.

The mean score for all synthesis items was reported earlier as 4.70. The mean score for each class section was computed and is given in Table 10. Examination of these data also increases one's confidence that the greater proportion of eligible learners successful in synthesizing in treatment X_2 was due to the treatment, and not to some undetermined bias among class sections.

Table 10. Mean Score on Synthesis Items for Each Class Section

	Section A	Section B	Section C	Section D
Mean Score on Synthesis Items	4.68	4.50	4.60	4.68

The results obtained support the idea that the timing of presentation of A and B is an important variable in the process of synthesis. This is consistent with Ausubel's theory that cognitive framework facilitates the processing of information. The results also suggest that A and B should be taught together to maximize the synthesis process.

Cueing Effects of Testing

The tests which evaluated success in synthesis were given twice. The first test contained only the synthesis items. After that was completed and handed in, a test evaluating the entire hierarchy and including the same questions testing for synthesis of C was given. It was proposed that some students would not succeed in synthesis at the first attempt but the cueing effect provided by the questions evaluating the entire hierarchy would enable them to succeed the second time. The data in Table 11 indicated that this did in fact occur.

Table 11. Success in Synthesizing C Due to Cueing Provided by the Hierarchy

Unit	Total No. of Eligible Learners	No. Synthesizing C on the First Test	No. of Additional Students Synthesizing C After Cueing
1	86	50	4
2	42	21	12
3	51	23	3
4	73	69	4
5	31	7	6
6	52	14	24
7	60	27	18
8	19	9	9

Correlation Between I.Q. and Ability to Synthesize

There were a total of 15 synthesis items in all the units. The highest total score for any student was 13 and the lowest score was 1. Therefore every learner was successful in synthesizing at least once. The mean score was 4.7 or, on the average, 31% of all the synthesis items were answered correctly.

The ability to synthesize A and B to produce C is not the same for all learners. Smith (1970) found that intelligence, as measured by I.Q. tests, made a significant contribution to the variation in scores on the synthesis process. In this study the correlation between I.Q. and success in synthesizing C was calculated using the procedure described in Winer (1962). The correlation found was .36, which is in good agreement with the results reported by Smith (1970). This correlation of .36 is significant at the .005 level. This suggests that the mental ability that I.Q. tests purport to measure is related to the ability to synthesize as defined by the criterion tests in this study.

SUMMARY AND CONCLUSIONS

The conclusions that could be drawn from the research will be directed towards answering these basic questions:

1. Is the proportion of "eligible" learners successful in achieving synthesis of C higher when A and B are presented together, than when A and B are presented separately?

2. Is the proportion of "eligible" learners (ones who have acquired both A and B) higher when A and B are presented together than when A and B are presented separately?

3. Are the proposed hierarchies valid?

4. Does a "cueing effect" exist which enables learners to succeed in synthesizing only after being tested for the lower part of the hierarchy?

5. Is the ability to synthesize correlated with I.Q.?

Synthesis is one of the higher cognitive processes (level 5.00 on the Taxonomy) and is of particular interest because this process results in the production of new knowledge. Information storage appears to significantly affect synthesis; specifically the presentation of relatable information at the same time favors the process of synthesis. The proportion of eligible learners successful in synthesizing A and B to produce C was higher for treatment X_2 than for treatment X_1 for units 1, 3, and 6. These differences were significant at the .05 level for units 1 and 6, and at the .01 level for unit 3.

These data clearly suggest that synthesis of relatable information to produce a new concept or abstration is more likely to occur if the presentation of the relatable subordinate concepts are contiguous in time. One may reasonably infer that in cases where the teacher wishes the student to perform this kind of synthesis, that information which is to be incorporated into the synthesis should be presented as close in time as practical considerations will allow. But it is also clear that practical considerations do not allow contiguous presentation of information that one expects the student to use in subsequent syntheses. The bald fact that it often takes more than one class period to develop a single subordinate concept precludes the presentation of all subordinate information at the same time.

In view of the results of this study and the obvious practical constraints cited above, one may reasonably ask if there is a practical

procedure that a teacher can use to enhance a student's ability to synthesize. Our data do not answer that question but they do suggest an hypothesis that is worth investigation.

It should be noted that when students were tested on the subordinate concepts, A and B, and were then asked to answer a question which required a synthesis of A and B, a substantial number of students who had previously failed the synthesis item were able to respond correctly. (See Table 11.) It should be further noted that in the experimental procedure, students were taught the subordinate concepts A and B during the week preceeding the testing. These concepts were then reviewed on the days immediately preceeding the day of testing; for treatment X_1 on the two preceeding days and for treatment X_2 on the immediately preceeding day. These data suggest that a practical procedure for assisting students in the development of synthesis skills would be to review information that is important to a given synthesis at the time that the synthesis is required. This review could be done in a relatively short period of time even though the instruction required to develop the subordinate concepts required several days for each concept.

It can be argued that such a review of subordinate concepts at the time the student is asked to perform a synthesis of this information is "cheating" and that the resultant student performance is not synthesis in a true sense. This argument is well taken. However, synthesis in a pure form is a very complex process which is likely to be developed over a long period of time. It can be argued that the instructional strategy suggested here, while not synthesis in the best sense of the term, would constitute one step in the development of the skill to perform syntheses without the aid of such obvious cues as the suggested review. It must be emphasized that our research does not provide data which prove that the suggested instructional strategy would be effective. Our data do suggest that investigation of such an instructional strategy would constitute a useful piece of research.

We should not leave the discussion of the effect of time of presentation on the ability of students to synthesize without noting that we found significant differences on only three of the eight units employed in our study. Clearly time of presentation is not the only variable that affects the student's ability to perform a synthesis nor is it such an overriding consideration that it masks the effect of other variables. Many students who were presented concepts A and B on separate days (treatment X_1) were successful on the synthesis items and conversely, many students who were presented concepts A and B on the same day (treatment X_2) were not successful on the synthesis items. Indeed, the proportions of students who were successful under the two treatments was so nearly the same for five of the eight units that we must attribute these differences to chance alone. Why is this so? The answer to this question is not clear from our data and we can only offer suppositions. One obvious explanation for the fact that

significant differences were found for three of our experimental cases and not for five is that our experimental procedures were not uniformly reliable; that differences in the quality of the instructional units, reliability of the grading, or validity of the hierarchies somehow combine to reduce the power of our test even though the effect of the time variable is constant over all units. This possibility is real. However, examination of the proportion of eligible learners (Table 7), the consistency ratios for the hierarchies (Table 6), and the interjudge reliabilities (Table 5) produces no obvious relation between these possible confounding variables and the results in question. We must assume that there are other variables that affect the student's ability to synthesize, that these variables were not identified in this study, and that these variables are sufficiently powerful to mask the effect of time in five out of eight cases examined. Again the question, what are those variables?

Based on intuition, a substantial body of research on transfer of training, and a subjective, post hoc examination of the instructional units used in this study, the following is suggested as a variable in the process of synthesis which is worth investigation. The variable is the number of common elements between the subordinate concepts A and B, that are involved in the synthesis. This is a variable that might easily interact with the variable of time as investigated in this study. Our argument is as follows:

Synthesis is a process that clearly involves transfer of training. The essential element of a synthesis is to take information that has been previously learned and to use that information in some new context to produce an abstraction that did not previously exist in the mind of the student. The body of research on transfer of training clearly suggests that the probability of transfer is increased by increasing the number of elements which are common to the learning task and the transfer task. It follows that a student is more likely to see the relationship between some subordinate concept A and another subordinate concept B if there are elements of commonality between the two subordinate concepts. It also follows that such elements of commonality are likely to be more obvious if the two subordinate concepts are juxtaposed as is the case when they are presented at the same time, than if these subordinate concepts are presented on different days. It is possible that it is the perception of these common elements, enhanced by the presentation of subordinate concepts A and B at the same time, that is important to the synthesis of this information to perform some new task. If this is true (and we have no data to show that it is) then the presentation of two subordinate concepts together in time would improve the ability of the student to synthesize only if common elements exist between the two concepts and these common elements are perceived by the student. Investigation of this proposition would require considerable skill on the part of the investigator but the proposition is sufficiently intriguing and the process of synthesis so important to education that such research should be undertaken.

The information concerning the effect that the time of presentation of A and B has on the synthesis of C represents the major contribution of this study. However, there were other results which are of interest because of their relationship to Ausubel's learning theories, Gagne's analysis of learning tasks into hierarchies, and the cueing effect of one test item on student performance on later items in a test.

There was no significant difference between treatments in the proportion of learners who successfully acquired both A and B. Ausubel's theory suggests that the presentation of A and B together would facilitate learning by utilizing the appropriate ideational anchorage. It is quite possible that this did not occur because of the similarity of the basic cognitive structure that existed in all successful learners. Therefore, all learners had equal ability to learn the informational concepts A and B. The results obtained may also be due to the method of presentation used because the programmed learning format probably minimizes the requirements of the learner to process information. Presentation of A and B in a less explicit way (one which requires the learner to process the information on his own instead of leading him to the appropriate conclusions through the questions given) might be a more appropriate test of Ausubel's theory.

The consistency ratio of the hierarchies was found to be uniformly high. This suggests that it is possible to construct valid hierarchies, and these hierarchies can be used to design appropriate teaching strategies. For example, in the hierarchies considered, it is necessary for the learners to acquire both A and B before they can succeed in acquiring C. However, the acquisition of A and B does not necessarily mean that the learner will be able to synthesize them to produce C by himself.

If the learner fails to acquire either A or B or both, he is not expected to succeed in producing C, and he will not be able to understand C except as rotely learned information.

A substantial number of students who failed to synthesize C when the test item was presented alone were successful in synthesizing C on the examination which tested the entire hierarchy. This can be attributed to the cueing effect of the test items and test construction. This finding verifies the results obtained by Harke (1969) which revealed a cueing effect when students were asked to solve a physics problem and were also provided with multiple choice questions on the same problem.

The cognitive ability described as synthesis may be closer to the goals of science instruction than any other. This study indicates

that the presentation of information at the same time facilitates the ability of the learner to synthesize. The question of whether the ability of individual learners to synthesize can be increased is unanswered by this study and merits further investigation. Areas of investigation that the author considers important have already been suggested.

The results of this study apply to the experimental population and generalization beyond this population must be made with caution. A replication of this research with a larger sample which involves many teachers is in order. This larger study could explore the effect of teaching style on the ability of synthesize. One would speculate that teachers who are indirect and non-authoritarian are more likely to encourage and reward speculative and creative thinking on the part of the students, and therefore these students would be more successful in synthesizing.

The ability to synthesize should be a general cognitive ability which extends across subject matter areas. This research only applies to chemistry, but one would expect similar results in other subject matter areas such as social studies, math, and German. Research in other areas with the assistance of subject matter experts is recommended.

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APPENDIX

Written Instructional Material and Criterion Tests for Each Unit

Unit 1. Programmed Learning Material Concerning A

There are limitations in the measurement of any quantity and therefore we cannot measure any object exactly. The limitations are due to various factors such as skill of the experimenter, imperfections in the instrument, random variation, accuracy of eyesight of observer, etc., but most importantly the limitation in the measuring instrument itself. In practice, one can adjust for random variation by taking an average; with enough experience one becomes skillful in operating the measuring devices and includes accuracy of eyesight, etc. as a part of the uncertainty estimated; and so we will be concerned primarily with the uncertainty of the measurement due to the instrument itself. This uncertainty must be large enough so the true value of the measurement will be reasonably sure to be between the largest and smallest values of your measurement. For example: $26.4 \pm .2$ means that the true value is somewhere between 26.2 and 26.6. The true value could be 26.2 or 26.3 but our best approximation is 26.4.

Now we can not know the true value but we can put limits on it. For example, I may not know my true weight but surely it is more than 100 lb. and less than 300 lb. This can be expressed as 200 ± 100. The 200 is my estimate of the true value and 100 is the uncertainty. In making a measurement we want to know as much as possible, so if I could use a better instrument perhaps I could say my weight is 196 ± 2. That means I weigh between 194 and 198. In order for this measurement to be valid, my true weight must be between 194 and 198. Our objective is to secure the minimum uncertainty for which we are reasonably certain our measurement is valid. Thus the measurement $197.89424 \pm .00003$ is valid only if we are reasonably certain that the true value is between 197.89421 and 197.89427. While this is possible, it is evident that it would require an excellent balance.

As we have previously stated, the principle source of uncertainty is usually the instrument, although, if one has a sufficiently good instrument, variations in the object itself may become significant. A beaker of water on a sensitive balance would show a decreasing reading as the water evaporates. Ordinarily this is not a problem because the water does not evaporate rapidly enough to be noticeable. If evaporation was too rapid we would use a closed container.

Even if we weigh an object which itself is essentially constant, there will be uncertainty due to the limited sensitivity of the balance. By sensitivity we mean the ability of the balance to respond to a small change. If we have a balance in apparent balance we can add a weight to one side and change the balance - but there is a limit to the size of weight we can add. If we choose a small enough weight we will not notice a change in the balance. An example is the addition of a grain of sand to a truck which already contains 20 tons of sand. The largest amount of weight that can be added without noticeably changing the balance is the sensitivity of the balance. This is why the uncertainty of the centigram balance in the lab is .01 grams, although one can <u>read</u> the balance more accurately. The larger capacity balances in the lab have a sensitivity or uncertainty of about .05 grams.

The balance itself may have been made improperly so that it consistently weighs .2 grams too much or too little. One can detect an error of this type by using a standard weight, but <u>not</u> by repeated weighings on that balance. One can also weigh the object on several different balances and by averaging, get a best value for the mass. If the following weights are obtained: 26.32, 26.33, 26.32, 26.35, the best value would be 26.33. The best value is obtained by rounding off the average, and the uncertainty includes the highest and the lowest values obtained in the series of measurements. 26.33±.02 means the weight is between 26.31 and 26.35. All of our measurements lie within that range and we are therefore reasonably sure that this is a valid measurement. This is the method used when one can make several measurements of a quantity.

1. Why does a single measurement made by an observer using a perfect instrument contain some uncertainty?

2. The uncertainty in a measurement may be due to error in the instrument and the lack of sensitivity of the instrument. Explain what is meant by error in the instrument and sensitivity using a balance as the instrument.

3. What is a valid measurement?

4. Given the following measurements find the best value for the mass of the empty beaker and give the uncertainty. Explain how you got your answer.

   38.2
   38.3
   38.1
   38.2
   38.2

Answers

1. There is always some uncertainty in reading an instrument because the graduations are not infinitely small. In addition the object may vary so that there is a chance of variation in the reading. In practice we correct for this by averaging the readings.

2. There is a limit to the ability of an instrument to respond to small changes. For example if a balance is apparently in balance we can add a weight so small that it will not produce a noticeable change in the balance position. Still, the weight on the balance pan has been changed, but the balance did not respond.

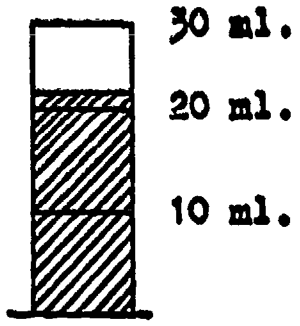
3. A valid measurement is one for which we are reasonably sure the true value lies within the range of uncertainty. For example $26.7 \pm .1$ is valid if the true measurement is between 26.6 and 26.8 ml.

4. The value of $38.2 \pm .1$ is obtained by averaging these values. Since all the measurements are in the range from 38.1 to 38.3 this is our best value.

Unit 1. Programmed Learning Material Concerning B

All measurements contain some uncertainty and we need to learn how to estimate the uncertainty of a measurement. Every measurement is an approximation and should include some indication of the uncertainty. For example, the width of this paper is $8.5 \pm .1$ inches. The range of a measurement is the largest and the smallest possible values. The range of the width of this paper is 8.4 in. to 8.6 in. When two or more measurements are combined, the uncertainty of each measurement contributes to the uncertainty in the combination.

Here is a diagram of a graduated cylinder which contains a liquid.



1. What would you give for the best value of the volume of the liquid?

2. Estimate the uncertainty.

3. Give the range of the measurement.

4. The measurement with its estimated uncertainty is ________ ± ml.

Look for the answers on the next page.

Answers

1. 23 ml. The answer should not be 23.0 ml. since that implies we can judge the tenths of ml. Actually we are guessing at the number of ml. since there is a mark only for each 10 ml. If you estimated the answer as 22 ml. or 24 ml., these answers are both correct since they fall within the range of 22 to 24.

2. The uncertainty is $\pm$ 1 ml. This means that although our best guess for the volume is 23 ml. it could be as small as 22 ml. or as large as 24 ml.

3. 22-24 ml. is the range of the volume since 22 is the smallest value and 24 is the largest value that is likely.

4. 23$\pm$1 ml. is the measurement and its uncertainty.

Unit 1. Criterion Test

1. Why does a single measurement made by an observer using a perfect instrument contain some uncertainty?

2. The uncertainty in a measurement may be due to error in the instrument and the lack of sensitivity of the instrument. Explain what is meant by error in the instrument and sensitivity using a balance as the instrument.

3. What is a valid measurement?

4. Given the following measurements find the best value for the mass of the empty beaker and give the uncertainty. Explain how you got your answer.

   101.42
   101.43
   101.41
   101.42
   101.43

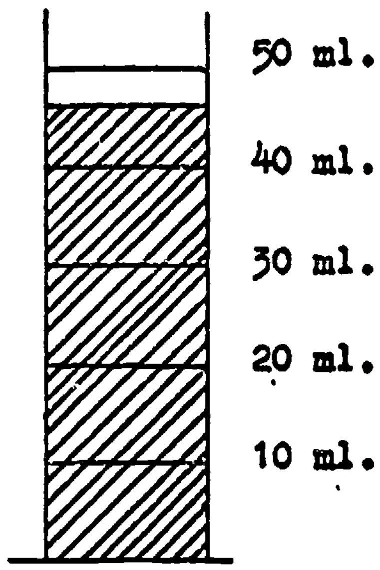
5. A chemical is added to the beaker and it is again weighed. However, the beaker exceeds the capacity of the centigram balance and a larger balance is used giving these data:

   156.50
   156.45
   156.45
   156.55
   156.50

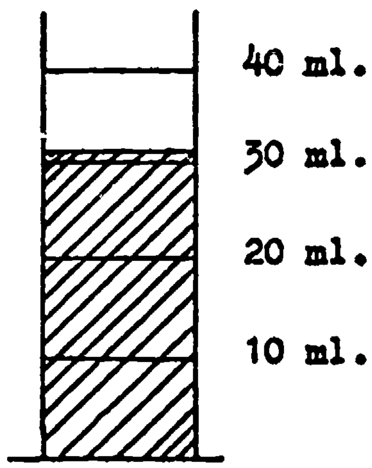
   Find the best value and the uncertainty of the beaker and acid, and explain how you got it.

6. Find the mass of the contents of the beaker and the uncertainty in the mass, and explain your answer.

7. The diagram shows a graduated cylinder which contains a liquid A. Give the volume of the liquid and estimate the uncertainty - explain your answer.



8. The diagram shows a graduated cylinder which contains the remainder of liquid A, after part of the liquid is poured into a beaker. Give the volume of liquid A which remains and estimate the uncertainty. Explain your answer.



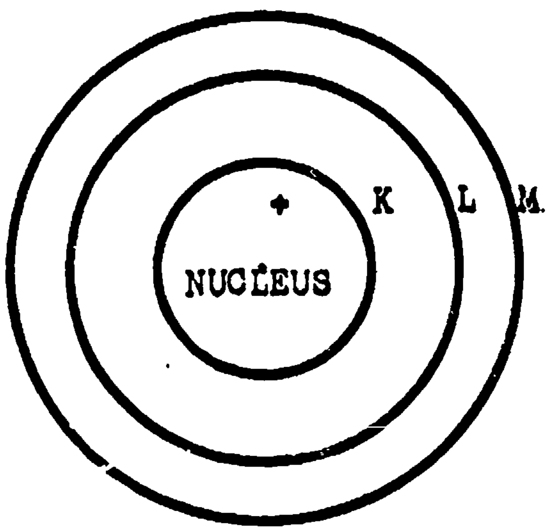
9. Find the volume of liquid A in the beaker and the uncertainty in the volume. Explain your answer.

Unit 2. Programmed Learning Material Concerning A

All atoms are composed of protons, neutrons and electrons. The Protons have a mass of 1 atomic mass unit and a charge of +1, the neutrons a mass of 1 atomic mass unit and a charge of 0, and the electrons the very small mass of 1/1836 atomic mass unit and a charge of -1. These particles are located in two parts of the atom called the nucleus and the shells.

The protons and neutrons are located in the nucleus of the atom. The nucleus is the very small center of the atom but it contains more than 99.9% of the mass of the atom, while occupying less than one billionth of the volume of the atom. The electrons have a very small mass and therefore can move rapidly. By constant rapid motion the electrons effectively occupy the space around the nucleus and exclude other electrons from this space. In this way the electrons make up the volume of the atom.

The electrons are arranged in shells or energy levels around the atom and these shells represent two aspects of the electrons. One is a region of probability of finding the electron which is usually a thin spherical shell. Secondly, the shells correspond to energy levels. An atom is typically represented in a drawing as follows:



The shells are designated alphabetically by letters beginning with K for the first shell and each shell can contain, at most, a particular number of electrons which corresponds to the shell. These numbers for each shell are K=2, L=8, M=18, N=32, etc. When an inner shell is filled, the remaining electrons must go into a higher shell because the space occupied by the electrons in the filled shells excludes the added shells.

Since our model of the atom represents shells as forming concentric spheres around the nucleus, adding a shell with a larger radius makes the atom larger. An atom such as Phosphorus (P) which contains 15 electrons will have 2 in the K shell, 8 in the L shell, and the remaining 5 in the M shell. Therefore P has three shells fully or partly occupied. P would be a larger atom than Carbon (C) which has 6 electrons, 2 in the k shell and 4 in the L shell.

The number of electrons in an atom is equal to the atomic number. The atomic number is the whole number which is given on the periodic chart.

1. How many electrons does an atom of aluminum (Al) have? ____________

2. How many electrons does an atom of chromium (Cr) have? ____________

3. How many shells are occupied in copper (Cu)? ____________

4. How many shells are occupied in boron (B)? ______________

5. Which atom is larger beryllium (Be) or magnesium (Mg)? ____________
   Explain your answer.

6. Which atom is larger helium (He) or sulfur (S)?________________

Answers

1. Aluminum has 13 electrons.

2. Chromium has 24 electrons.

3. Copper has 29 electrons: 2 in the K shell, 8 in the L, 18 in the M and 1 in the N, which makes 4 shells.

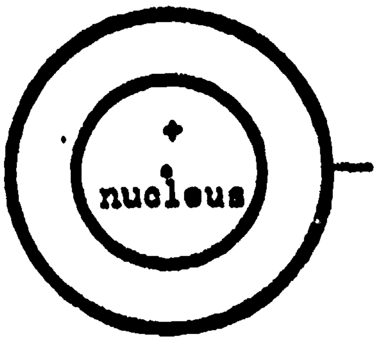
4. Boron has 4 electrons: 2 in the K shell and 2 in the L, which makes 2 shells.

5. Magnesium has 3 shells and beryllium has 2 shells, therefore magnesium is the larger atom.

6. Helium has 1 shell and sulfur has 3 shells, therefore sulfur is larger.

Unit 2. Programmed Learning Material Concerning B

An atom is made up of a positively charged nucleus which is very small surrounded by negative electrons in a generally spherical distribution as pictured.



The electrons define the size of the atom by rapidly moving around in the region around the nucleus and excluding other electrons from that space. The negative electrons are attracted to the nucleus by the positive charge produced by the protons. The charge of the nucleus is determined only by the number of protons in the nucleus since the neutrons which are also in the nucleus have a charge of 0.

The larger the number of protons in the nucleus the greater its positive charge, and consequently the greater the force exerted on the negatively charged electrons. As this attracting force becomes greater, the atom becomes smaller, since the electrons are attracted closer to the nucleus by the greater nuclear force. Each electron is affected independently by the nuclear charge so the attracting force of chlorine (Cl) with its 17 protons is greater than that of sodium (Na) with its 11 electrons. The additional electrons of chlorine do not decrease the attracting force of the nucleus so the attracting force depends on the charge of the nucleus and not on the number of electrons in the atom.

The number of protons in the nucleus of an atom can be found by looking at the atomic number of the periodic chart. The atomic number is always a whole number. For example, the number of protons in krypton (Kr) is 36.

1. What is the number of protons in calcium (Ca)?

2. What is the number of protons in beryllium (Be)?

3. Which atom has the greater attracting force in the nucleus, magnesium (Mg) or sulfur (S)?

4. Which atom has the greater attracting force in the nucleus, phosphorus (P) or nitrogen (N)?

5. Which atom is the smaller, sodium (Na) or aluminum (Al)?

6. Which atom is smaller, nickel (Ni) or iron (Fe)?

Turn to the next page for the answers.

Answers

1. Calcium (Ca) has 20 protons.

2. Beryllium (Be) has 4 protons.

3. Magnesium (Mg) has 12 protons in the nucleus and sulfur (S) has 16 protons, therefore sulfur has the greater attracting force in the nucleus.

4. Phosphorus (P) has 15 protons in the nucleus and nitrogen (N) has 7 protons, therefore phosphorus has the greater attracting force in the nucleus.

5. Sodium (Na) has 11 protons and aluminum (Al) has 13 protons, therefore aluminum exerts a greater attracting force on its electrons and is the smaller atom.

6. Nickel (Ni) has 28 protons and iron (Fe) has 26 protons, therefore nickel exerts a greater attracting force on its electrons and is the smaller atom.

Unit 2. Criterion Test

1. The number of protons in lead (Pb) is :

2. Which of the following has the greatest nuclear charge: iron (Fe), nickel (Ni) or cobalt (Co)? Explain your answer.

3. Which of the following nuclei exerts the greater force on its electrons: carbon (C), nitrogen (N), or oxygen (O)? Explain your answer.

4. Which has the largest atomic radius: silicon (Si), phosphorus (P) or sulfur (S)? Explain your answer.

5. Describe briefly the nucleus and shells of the atom and include a drawing.

6. Nearly all the volume of the atom is occupied by ________________.

7. Give the maximum number of electrons in the following shells: K_____, L______, M______, N______.

8. Does the adding of a shell make the corresponding atom larger or smaller or does it remain the same?____________________________. Explain your answer.

9. Potassium (K) has a diameter of 2.03 angstroms which is larger than the diameter of bromine (Br) 1.14 angstroms. Explain why.

10. Sodium (Na) has a diameter of 1.57 angstroms which is larger than the diameter of aluminum (Al)(1.25 angstroms). Explain why.

11. Chlorine (Cl) has a diameter of .99 angstroms which is larger than the diameter of fluorine (F) .72 angstroms. Explain why.

12. Neon is larger than helium. Explain why.

13. Sulfur (S) has a diameter of 1.04 angstroms which is larger than the diameter of oxygen (O) .74 angstroms. Explain why.

14. Magnesium (Mg) has a diameter of 1.36 angstroms and the diameter of tellurium (Te) is 1.35 angstroms and these are nearly equal in radius. Explain why.

15. Lithium (Li) has a radius of 1.23 angstroms and this is nearly equal to the radius of vanadium (V) which is 1.22 angstroms. Explain why.

Unit 5. Programmed Learning Material Concerning A

All molecules of a liquid are in continuous random motion, and while some molecules are moving very rapidly and others very slowly at a given temperature, there is a definite average molecular motion. The average molecular motion of a substance is proportional to the temperature. When the temperature of a substance is increased by heating it, this addition of energy increases the average molecular motion. For liquids this increased motion is primarily exhibited in the vibration of the molecules. The greater the energy of a liquid the greater the average back and forth vibration of its molecules. This vibration affects the volume the liquid occupies, because as the vibration increases, the effective space occupied by the molecule increases; and so the volume of the liquid increases. We have restricted the discussion to liquids so far, because although the same effect is true in general for solids and gases, there are important differences between liquids and solids and gases that will not be discussed at this time.

1. As the temperature of a liquid decreases, the average molecular motion ________________________. Explain.

2. As the motion of the molecules in a liquid increases, the volume occupied by the liquid ________________________. Explain.

Look at the answers on the next page.

Answers

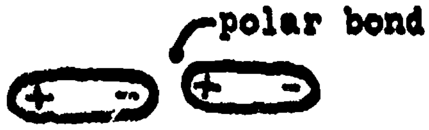
1. Decreases. The average energy of the molecules decreases as the temperature is decreased, and since this energy is mainly shown as molecular motion the average molecular motion also decreases.

2. Increases. As the molecular motion increases this is reflected in a greater vibration of the molecules. This greater vibration increases the effective space occupied by a molecule, and the volume of the liquid increases.

Unit 3. Programmed Learning Material Concerning B

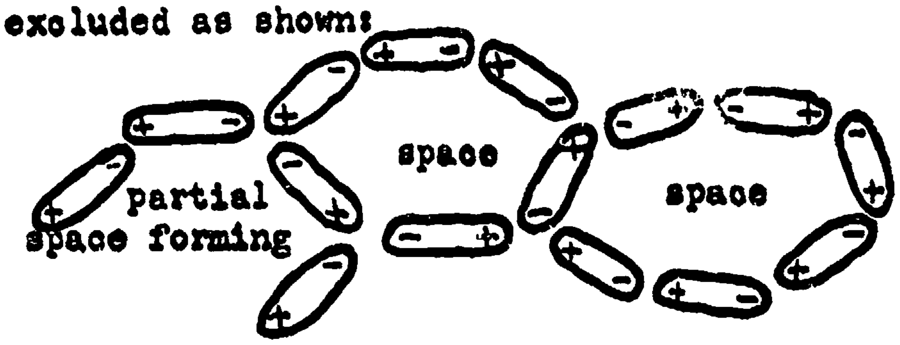
A polar molecule has an uneven distribution of electrons, causing one end to be slightly negative and the other end to be slightly positive as shown in the diagram:

Water is one of the many substances whose molecules are polar. The attraction of the oppositely charged ends of these molecules causes them to form polar bonds as shown:



Although this bond is rather weak and is often broken by the random vibration of the molecules, these bonds attach two or more molecules together for a short time and at equilibrium when one bond is broken another tends to form at the same time. The number of these bonds that exist at any one time is constant and determined by the average molecular motion.

In water, these polar bonds tend to link the molecules into an open structure which contains spaces from which other water molecules are excluded as shown:



Not pictured are the many molecules of water that are not bonded but are moving independently.

This means that the formation of polar bonds increases the volume of a given amount of water. At a given temperature the number of bonds that exist at any given time is constant, because although some are being broken, an equal number is being formed. As the temperature is increased the molecules have more energy and some of the bonds are broken. This means that the number of polar bonds that exist at any given time is decreased as the temperature is increased.

1. Describe a polar molecule and explain why it occurs using a drawing.

Look for the answer on the next page.

2. Describe a polar bond and explain why it occurs using a drawing.

Look for the answer on the next page.

3. Use a drawing to illustrate the effects of the formation of polar bonds on the volume of water.

Look for the answer on the next page.

4. As the temperature of water molecules is decreased, the formation of polar bonds between molecules is ________________. Explain.

Look for the answer on the next page.

5. As more polar bonds are formed, the volume of the water ___________. Explain.

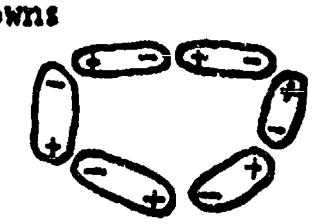
Look for the answer on the next page.

Answers

1. A polar molecule has an unequal charge distribution. One end is slightly positive and the other end is slightly negative, due to unequal sharing of the electrons and looks like:

2. A polar bond is the bond between two polar molecules caused by the attraction of the + end of one molecule for the negative end of another molecule as shown:

3. The formation of polar bonds in water, creates a structure with open spaces as shown:



from which other molecules are excluded. This makes the volume of a given amount of water larger.

4. <u>increased</u>. The molecules have less energy, and so fewer of the polar bonds formed are broken by the random molecular motion.

5. <u>increases</u>. As more polar bonds are formed, there are more open spaces from which water molecules are excluded, and the volume of a given amount of water increases.

Unit 3. Criterion Test

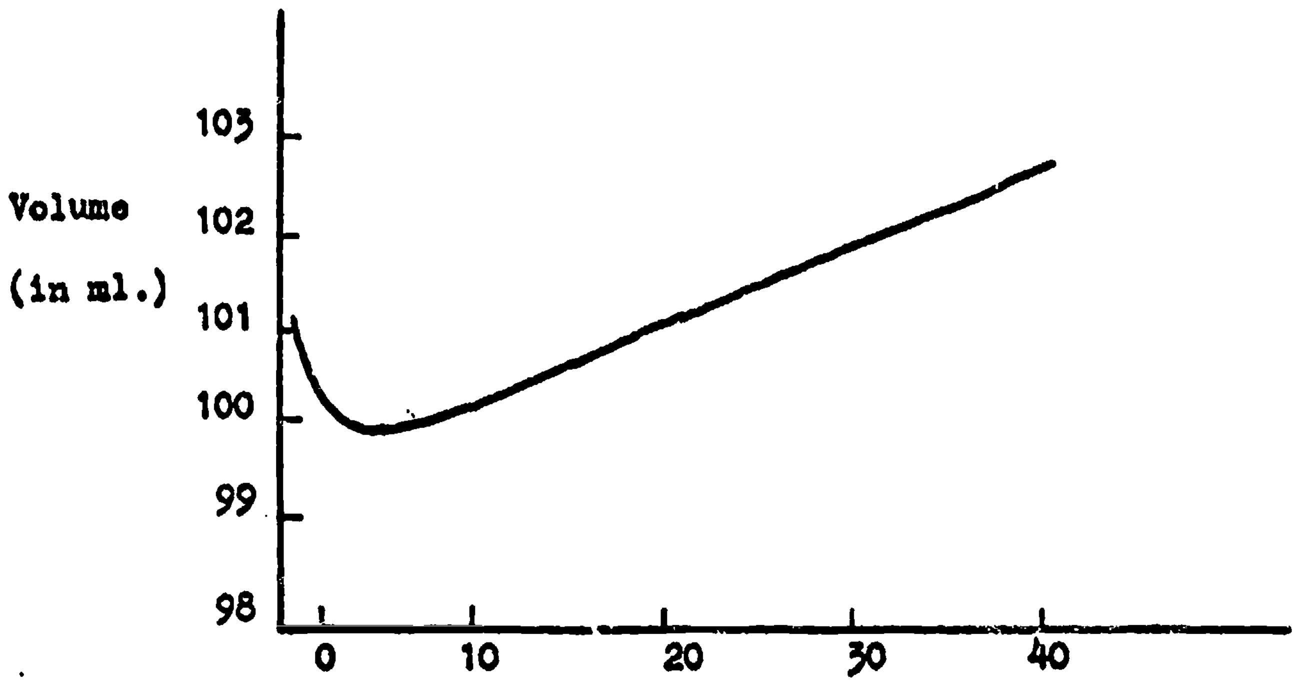
1. As the temperature of the water decreases, does the average molecular motion increase, decrease, or stay the same?

2. As the motion of the water molecules decreases, does the space occupied by a molecule increase, decrease, or stay the same? Explain your answer.

3. As the temperature of water molecules is decreased, is the formation of Hydrogen bonds between the water molecules increased, decreased or does it stay the same?

4. Does the increased formation of Hydrogen bonds cause the volume of the water to increase, decrease or stay the same? Use a diagram to explain your answer.

Volume Vs. Temperature (for 100 grams of H_2O)



Temperature in Degrees Centigrade

5. Explain in terms of the behavior of the molecules, why the volume of the water decreases as the temperature is decreased; reaches a minimum at 4 degrees C., and then the volume of the water increases as the temperature is decreased still more.

Unit 4. Programmed Learning Material Concerning A

A chemical formula represents all of the following:

a. which elements are present in the compound
b. how many atoms are present in one molecule
c. the ratio of atoms of one element to atoms of another element

For example, one molecule of $AlCl_3$ contains one atom of Al and three atoms of Cl.

The formula of a substance is obtained by analyzing the compound. The formulas obtained are expressed as the lowest whole number ratio of atoms by convention and are called simplest formulas. Therefore the formula for water is written H_2O and not H_4O_2 or H_6O_3.

1. What is the ratio of atoms of carbon (C) to chlorine (Cl) in CCl_4?

Look for the answer on the next page.

2. What is the ratio of atoms of phosphorus (P) to oxygen (O) in P_2O_5?

Look for the answer on the next page.

3. What is the ratio of potassium (K) atoms to sulfur (S) atoms in K_2SO_4?
What is the ratio of sulfur (S) atoms to oxygen (O) atoms?
What is the ratio of potassium to oxygen atoms?

Look for the answer on the next page.

1. In CCl_4 the ratio of carbon to chlorine atoms is 1 to 4.

2. The ratio of phosphorus to oxygen atoms in P_2O_5 is 2 to 5.

3. The ratio of potassium to sulfur atoms in K_2SO_4 is 2 to 1.

   The ratio of sulfur to oxygen atoms is 1 to 4.

   The ratio of potassium to oxygen atoms is 1 to 2 (this is the same as 2 to 4 but it is customary to reduce the ratio to its smallest terms).

Unit 4. Programmed Learning Material Concerning B

In the early 1800's Amadeo Avogadro formulated the theory that equal volumes of all gases at the same conditions of temperature and pressure contain equal numbers of molecules. The qualification of equal temperature and pressure is important and is usually controlled by keeping the gases at standard temperature and pressure. STP is the abbreviation used for standard temperature and pressure and means a temperature of 273 degrees Kelvin and 1 atmosphere pressure. 273 degrees Kelvin is equal to 0 degrees Centigrade (Celsius) and to 32 degrees Fahrenheit; and 1 atmosphere of pressure is the pressure of dry air at sea level which is equal to 14.7 pounds per square inch and to 760 millimeters of mercury in a barometer. In the following discussion all gases are at STP.

In a gas the molecules are moving very rapidly and are, on the average, quite far apart. For this reason the mass and radius of the atoms do not affect the volume of the gas. If the atoms were much closer together as they are in a solid, the radius of the atom would affect the volume but the mass would not.

The theory that equal volumes of gases contain equal numbers of molecules has been verified by many experiments. For example, two bottles, at STP, which contain 2.0 liters of NH_3 and 2.0 liters of N_2, contain equal numbers of molecules. A bottle which contains 3.0 liters of CO_2 has three times as many molecules as one which contains 1.0 liters of Ne at STP. This law holds regardless of the nature of the molecule. Diatomic molecules contain 2 atoms per molecule and examples are O_2, F_2, H_2 and CO. Monoatomic molecules contain one atom per molecule and examples are Ne, He, Hg and Na. Gases which contain three, four or five atoms per molecule also exist, and examples are CO_2, SO_3 and CCl_4. Not all of the substances mentioned are gases at STP (Hg and Na are not) but any substance can be changed into a gas if the temperature is high enough.

1. How would the number of molecules of O_2 in 5.0 liters compare to the number of molecules of NO_2 in 1.0 liters if both gases are at the same temperature and pressure.

   Turn the page for the answer.

2. How would the number of molecules in 3.0 liters of SO_3 compare to the number of molecules in 2.0 liters of SF_6 if both gases are at the same temperature and pressure.

   Turn the page for the answer.

1. There are five times as many molecules in 5.0 liters of O_2 as there are in 1.0 liters of NO_2.

2. There are three molecules of SO_3 for each 2 molecules of SF_6.

Unit 4. Criterion Test

1. The formula for calcium chloride is $CaCl_2$, therefore there are/is

   A. equal numbers of atoms of calcium and chlorine
   B. one calcium atom for two chlorine atoms
   C. two calcium atoms for one chlorine atom
   D. no specific relationship between the number of atoms of calcium and chlorine

2. What is meant by a diatomic gas?

3. When H_2O is analyzed the number of atoms of hydrogen and the number of atoms of oxygen obtained will be

   A. equal to each other
   B. two atoms of hydrogen for one atom of oxygen
   C. one atom of hydrogen for two atoms of oxygen
   D. no specific relationship between the number of atoms of hydrogen and oxygen

4. In 200 ml. bottle of neon gas and 100 ml. bottle of helium gas at the same temperature and pressure there is/are

   A. equal numbers of atoms in each bottle
   B. twice as many atoms of neon as helium in the bottles
   C. ten times as many atoms of neon as helium in the bottles
   D. there is no relation between the number of atoms of neon and helium

5. In bottles of the two diatomic gases A and B, at the same temperature and pressure, the number of atoms of A compared to B depends on

   A. the volume of the gases
   B. the mass of the atoms
   C. the radius of the atoms
   D. all of the above
   E. none of the above

6. A chemical substance is decomposed completely to give two different monoatomic gases A and B. The volumes of the gases are not equal; 2.0 liters of A are formed when 3.0 liters of B are formed. What is the formula for the original substance? Explain your answer.

7. When a substance is analyzed completely by electrolysis two different diatomic gases, X_2 and Y_2, are formed. The amount of each gas is not equal; 30 ml. of X_2 forms when 10 ml. of Y_2 forms. What is the formula for the original substance? Explain your answer.

Unit 5. Programmed Learning Material Concerning A

A liter is a unit of volume and is equal to 1000 ml. It is usually more convenient to measure the volume of a gas than to weigh it because the weight is so small. The amount of that gas is not specified however, unless the pressure and temperature are given. For example, 1 liter of O_2 gas at 10 atmospheres is far more oxygen than 1 liter of O_2 gas at one atmosphere of pressure. The temperature and pressure are commonly kept at standard conditions so the volumes can be compared. Standard conditions are a pressure of 1 atmosphere and 0 degrees Centigrade. One atmosphere is the pressure of the atmosphere at sea level and can also be given as 14.7 pounds per square inch or 76.0 cm. of mercury in a barometer. In a barometer 76 cm. is the height of a column of mercury that will be supported by a pressure of one atmosphere.

A mole of any gas occupies a volume of 22.4 liters at standard conditions. Thus 22.4 liters of oxygen is one mole and 44.8 liters of hydrogen is two moles at standard temperature and pressure.

1. What is the volume of 2.0 moles of CO_2 gas at STP?

2. What is the volume of .50 moles of argon gas at STP?

3. 67.2 liters of NH_3 gas at STP is how many moles?

4. 33.6 liters of N_2O gas at STP is how many moles?

Turn to the next page for the answers.

Answers

1. The volume of 2.0 moles of CO_2 at STP is 44.8 liters, since 22.4 liters equals one mole at STP.

2. The volume of .50 moles of argon (Ar) gas at STP is 11.2 liters, since 22.4 liters equals one mole at STP.

3. 67.2 liters of NH_3 gas at STP is 3.0 moles since 22.4 liters equals one mole at STP.

4. 33.6 liters of N_2O gas at STP is 1.5 moles since 22.4 liters equals one mole at STP.

Unit 5. Programmed Learning Material Concerning B

The amount of a substance can be determined by weighing it. In the chemistry laboratory the unit of mass (or weight) is the gram.

Chemical formulas can be written for many common substances such as water (H_2O, salt (NaCl) and carbon dioxide (CO_2). The formula gives the kind of atoms present and the number of atoms of each element in the molecule. For example, a molecule of sulfuric acid, H_2SO_4, is composed of 2 hydrogen atoms, 1 sulfur atom and 4 oxygen atoms.

The atomic weight of each element is given on the periodic chart and represents the weight of the average atom of that element compared to the weight of a carbon atom which is taken to be 12.0000. Thus Mg (24.3) atoms are a little more than twice as heavy as C (12) and He (4) is about 1/3 as heavy as C (12.0). The atomic weights are not usually whole numbers because the average includes isotopes of different weights, although many are close to whole numbers because a particular isotope is most common.

The formula weight of a substance is found by adding the atomic weight of each element as often as it occurs. For example, the formula weight of $CaCl_2$ is $40 + 2(35.5) = 111$ and for H_2SO_4, $2(1) + 32 + 4(16) = 2 + 32 + 64 = 98$.

1. What is the formula weight of NaF ______________?
2. K_2CO_3 ______________
3. CO_2 ______________
4. N_2 ______________
5. $(NH_4)_3PO_4$ ______________
6. $Al_2(SO_4)_3$ ______________

Turn to the next page for the answers.

The formula weight in grams of any substance is called a mole. For example, 98 grams of H_2SO_4 is one mole of H_2SO_4 and 222 grams of $CaCl_2$ is two moles of $CaCl_2$.

1. 22 grams of CO_2 is how many moles?

2. 63 grams of NaF is how many moles?

3. 3 moles of N_2 is how many grams?

4. .8 moles of $Al_2(SO_4)_3$ is how many grams?

5. 2.5 moles of K_2CO_3 is how many grams?

6. 196 grams of H_2SO_4 is how many moles?

Turn to the next page for the answers.

Answers

1. 22 grams of CO_2 = .5 moles since 44 grams = 1 mole of CO_2 (22/44 = .50)

2. 63 grams of NaF = 1.5 moles since 42 grams = 1 mole (63/42 = 1.5)

3. 3 moles of N_2 = 84 grams since 28 grams = 1 mole (3 x 28 = 84)

4. .8 moles of $Al_2(SO_4)_3$ = 273.6 grams since 342 grams = 1 mole (.8 x 342 = 273.6)

5. 2.5 moles of K_2CO_3 = 345 grams since 138 grams = 1 mole (2.5 x 138 = 345)

6. 196 grams of H_2SO_4 = 2 moles since 98 grams = 1 mole (196/98 = 2)

1. The formula weight of NaF is 23 + 19 = 42.

2. The formula weight of K_2CO_3 is 2(39) + 12 + 3(16) = 78 + 12 + 48 = 138.

3. The formula weight of CO_2 is 12 + 2(16) = 12 + 32 = 44.

4. The formula weight of N_2 is 2(14) = 28.

5. The formula weight of $(NH_4)_3PO_4$ is 3(14) + 12(1) + 31 + 4(16) = 42 + 12 + 31 + 64 = 149.

6. The formula weight of $Al_2(SO_4)_3$ is 2(27) + 3(32) + 12(16) = 54 + 96 + 192 = 342.

Unit 5. Criterion Test

1. Glucose has the formula $C_6H_{12}O_6$. Give the number of atoms of each element in one molecule of glucose.
   C ________
   H ________
   O ________

2. The atomic weight of potassium (K) is ____________________.

3. The formula weight of carbon dioxide (CO_2) is ____________________.

4. A mole of ammonia (NH_3) is ____________________ grams.

5. STP stands for (be specific) ______________________________

6. The mass of .7 moles of SF_6 gas at STP is ____________________.

7. The volume of two moles of SO_2 gas at STP is ____________________.

8. The volume of 1.85 moles of ClS gas at STP is ____________________.

9. The volume of 77 grams of CCl_4 gas at STP is ____________________.
   Explain how you obtained your answer.

10. The mass of 44.8 liters of CO_2 gas at STP is ____________________.
   Explain how you got your answer.

Unit 6. Programmed Learning Material Concerning A

Reactions take place when molecules collide with each other. The kinetic molecular theory states that:

1. all molecules are in constant motion
2. the motion of molecules is random
3. the molecules collide very frequently
4. collisions often result in a transfer of energy with one molecule gaining energy and the other losing energy
5. individual molecules at a given temperature do not all move at the same speed but the speeds vary over a large range
6. most molecules have the average velocity at a constant temperature
7. when the temperature of the molecules is increased by adding energy, the average speed of the molecules is increased, although there are still some slow and some fast molecules.

A simplified system of chemicals containing two gases will be considered. When the molecules collide the energy of collision varies greatly. If two molecules are moving in the same direction with one molecule moving faster and catching up to the other, the energy of collision will be relatively small. If the same molecules collide when moving directly toward each other, the energy of collision will be much larger. The molecules present have a large range of speeds and a collision between two molecules that are both moving very fast will produce more energy than a collision between two slow moving molecules.

For a given set of reactants, say hydrogen and chlorine, there is a certain minimal level of collision energy required if a reaction is to take place. If the energy produced is less than this amount the molecules will rebound uncombined. If the energy is greater than this a reaction will occur.

1. Do all molecules move at the same speed at a given temperature?

2. Do molecules collide with other molecules often?

3. Adding energy to increase the temperature of a substance makes the molecules move ______________________.

4. The energy of collision of two molecules depends on ______________ and ______________________.

Answers

1. No. Some molecules are moving very slowly and others are moving very rapidly although most molecules move with an average speed.

2. Yes, the molecules collide very frequently.

3. Faster

4. The energy of collision of two molecules depends on the speed and direction of their motion. The energy is greatest when the molecules are moving directly toward each other at high speeds.

Unit 6. Programmed Learning Material Concerning B

Reactions take place when molecules collide with each other. Some of the random collisions that occur are highly energetic and some have low collision energies. If a collision between two molecules is to produce a reaction it must produce a certain minimum amount of energy called the activation energy. The amount of the activation energy required depends on the nature of the reactants. Molecules which have a low activation energy are very reactive and thus readily combine with other molecules.

The activity of an element is related to many factors but can be generally determined by looking at the periodic chart. The elements on the left side of the chart are called metals and increase in activity as one goes down the chart. For example potassium (K) is more reactive than sodium (Na). The elements on the right side of the chart are called non-metals and decrease in activity as one goes down the chart. An example is bromine (Br) which is more active than iodine (I).

1. Collisions between molecules produce energy which can enable the molecules to react. The minimum amount of energy needed is called the _______________________.

2. Which is more active, barium (Ba) or strontium (Sr)?

3. Which is more active tellurium (Te) or selenium (Se)?

Answers

1. Activation energy

2. Barium (Ba)

3. Selenium (Se)

Unit 6. Criterion Test

1. As the temperature is increased what happens to the energy of collision? Explain your answer.

2. Explain why sodium (Na) reacts with sulfur (S) at room temperature while iron (Fe) does not react with sulfur (S) at room temperature.

3. At room temperature a mixture of nitrogen and oxygen does not react. At 400 degrees C. the reaction occurs. Explain why.

4. At room temperature (25 degrees C.) a mixture of chlorine and oxygen reacts, but a mixture of bromine and oxygen does not. Explain why.

H_2	H_2	H_2	H_2
Br_2	Cl_2	Br_2	Cl_2
25° C.	25° C.	285° C.	285° C.

5. There are two containers at room temperature (25 degrees C.). In one container equal numbers of molecules of hydrogen and bromine are mixed and in the other container equal numbers of molecules of hydrogen and chlorine are mixed. After several hours there is no evidence of a reaction in either container. When the temperature is increased to 285 degrees C. there is a reaction in the container which holds the hydrogen and chlorine but not in the container which holds the hydrogen and the bromine. Explain why the reaction occurs in one container and not in the other.

Ca	Ca	Ca	Ca
S	O	S	O
100° K.	100° K.	300° K.	300° K.

6. There are two containers at 100 degrees K. In one container there are equal numbers of molecules of calcium (Ca) and oxygen (O) and in the other container equal numbers of molecules of calcium (Ca) and sulfur (S) are mixed. After several hours there is no evidence of a reaction in either container. When the temperature of both is increased to 300 degrees K. there is a reaction in the container of calcium (Ca) and oxygen (O) but not in the container with the calcium (Ca) and sulfur (S). Explain why the reaction occurs in one container and not in the other.

Unit 7. Programmed Learning Material Concerning A

The molecules of a gas are relatively far apart and are in constant motion. The molecules occupy space by excluding other molecules from that space when they collide with them. As the temperature of a gas is increased the molecules gain energy and their average speed increases. The faster motion of the molecules allows each molecule to occupy more space and the total volume of the gas increases. Therefore heating a gas increases its temperature and its volume.

The temperature of gases is commonly measured in degrees Kelvin. The temperature in degrees Kelvin can be found by adding 273° to the centigrade temperature. Example: 10°centigrade is 283° Kelvin. If the temperature in ° Kelvin is doubled, the molecules move twice as fast and the volume is twice as large. If the temperature in ° Kelvin is 3.5 times greater, the volume is 3.5 times greater also.

1. In a gas are the molecules close together or far apart?

2. How do gas molecules occupy space?

3. As the temperature of a gas is increased the motion of the molecules ______________________.

4. As the temperature of the gas is increased, what happens to the volume of the gas? Explain your answer.

5. If the temperature of 5.0 liters of a gas is increased from 200° Kelvin to 600° Kelvin what happens to the volume? Explain your answer.

Answers on next page

Answers

1. In a gas the molecules are relatively far apart.

2. Gas molecules occupy space by moving and excluding other molecules from that space through collisions.

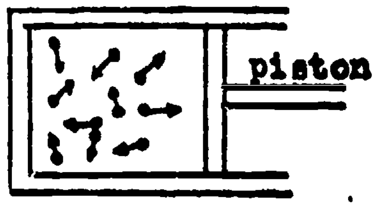
3. As the temperature of a gas is increased the molecules move faster.

4. As the temperature of a gas is increased the volume increases because the increased motion of the molecules allows the molecules to occupy more space.

5. Heat is added to increase the temperature and the molecules move faster and occupy a larger volume. In this case the temperature is three times greater and the volume will be three times greater or 15.0 liters.

Unit 7. Programmed Learning Material Concerning B

The molecules of a gas are relatively far apart and are in constant motion. The collisions of the gas molecules on the walls of the container are responsible for the pressure exerted by the gas.



In this diagram the gas molecules are contained by a piston in a cylinder. The pressure exerted by the piston on the gas is just equal to the pressure exerted by the gas on the container. If the piston is moved to the left, the molecules are forced to occupy a smaller volume. As the volume occupied becomes smaller, the molecules collide with the walls more frequently and exert a greater pressure on the walls of the container. The pressure of the gas molecules on the piston will again be equal to the new pressure of the piston on the gas molecules. Therefore decreasing the volume of a gas requires an increase of applied pressure and causes an increased pressure of the gas molecules. It is also true that increasing the pressure on a gas decreases the volume of the gas. The pressure of a gas is usually measured in atmospheres where one atmosphere is the pressure of the atmosphere at sea level. If the pressure is doubled to two atmospheres the volume is $\frac{1}{2}$ as much. If the pressure is five times higher the volume would be 1/5th as great.

1. In a gas are the molecules close together or far apart? Stationary or moving?

2. Explain how gas molecules exert pressure.

3. As the pressure on a gas is increased what happens to the volume of the gas? Explain your answer.

4. When the pressure of 6 liters of oxygen is changed from three atmospheres to two atmospheres, what happens to the volume? Explain your answer.

Answers

1. The molecules in a gas are relatively far apart and are in constant motion.

2. Gas molecules exert pressure by colliding with each other and the walls of the container.

3. As the pressure on a gas is increased the volume of the gas decreases because the gas molecules are forced to occupy a smaller volume to balance the increased pressure of the container.

4. Since the pressure is decreased the gas expands in volume. The new pressure is 2/3 of the original pressure so the volume will be 3/2 as large or 9 liters.

Unit 7. Criterion Test

1. In a gas the molecules are (small, large) distances apart and are always (stationary, in motion). Circle the correct answer.

2. When 2.0 liters of neon (Ne) gas is heated from 150° Kelvin to 300° Kelvin, what is the volume? Explain your answer.

3. When 3.5 liters of oxygen gas is heated from 200° Kelvin to 500° Kelvin what is the volume? Explain your answer.

4. When the pressure on 8.0 liters of helium (He) is increased from 2 atmospheres to 4 atmospheres, what is the volume? Explain your answer.

5. When the pressure on 12.0 liters of nitrogen is increased from 4 atmospheres to 6 atmospheres, what is the volume? Explain your answer.

6. When 16 liters of oxygen (O) gas at 200° Kelvin and 2 atmospheres of pressure is heated to 400° Kelvin while the pressure is increased to 4 atmospheres, what is the volume? Explain your answer.

7. When 4 liters of nitrogen(N) at 300° Kelvin and 1 atmosphere of pressure is heated to 450° Kelvin and the pressure is increased to 1.5 atmospheres, what is the volume? Explain your answer.

Unit 8. Programmed Learning Material Concerning A

A closed chemical system (one in which nothing is added or may escape) in equilibrium, under constant conditions, is a dynamic process in which two opposing reactions are occuring at equal rates. At equilibrium in the reaction:

$$A + B = C + D + \text{heat}$$

the number of molecules of A and B reacting to produce C and D and release heat at any one moment is equal to the number of molecules of C and D using up heat while reacting to produce A and B. The maintenance of this equilibrium requires constant conditions.

If any of the conditions change the concentrations of the substances present change to make a new equilibrium in a way that will remove the stress. For example, if heat is added, the system adjusts by changing the composition of the substances. In the reaction above the added heat will be absorbed by reacting C and D molecules and will produce more A and B molecules so the concentration of A and B will increase and the concentration of C and D will decrease. We then say the equilibrium has shifted to the left away from the added heat. In the equation: Heat + $NH_4Cl_{(s)}$ + H_2O = $NH_4Cl_{(aq)}$ the addition of heat would displace the equilibrium to the right.

1. What is a closed chemical system?

2. Write a chemical equation and use it to describe chemical equilibrium.

3. A change in a closed chemical system produces a stress on the equilibrium which is relieved by ______________________________

4. Explain why the addition of heat to the system in equilibrium described by the reaction:

$$H_2 + I_2 = 2HI + \text{Heat}$$

will cause the equilibrium to shift to the left.

Answers

1. A closed chemical system is one where nothing is added or permitted to escape. This includes molecules and heat.

2. In the reaction: Cu + S = CuS + Heat
at equilibrium the number of molecules of Cu combining with S to form CuS and release heat at any one time is equal to the number of molecules of CuS absorbing heat and splitting to form Cu and S molecules.

3. A change in a closed chemical system produces a stress on the equilibrium which is relieved by a change in the concentrations of the reactants and the products.

4. The addition of heat causes more HI molecules to split into H_2 and I_2 molecules and the concentration of H_2 and I_2 increases to relieve the stress imposed by the addition of heat. The equilibrium is shifted to the left.

Unit 8. Programmed Learning Material Concerning B

A closed chemical system (one in which nothing is added or may escape) in equilibrium under certain conditions is a dynamic process in which two opposing reactions are occuring at equal rates. At equilibrium in the reaction:

$$A + B = C + D + \text{Heat}$$

the number of molecules of A and B reacting to produce C and D and give off heat at any one moment is equal to the number of molecules of C and D absorbing heat and reacting to produce A and B. The maintenance of this equilibrium requires constant conditions.

A change in pressure could upset the equilibrium and the system would react to relieve the stress produced. For example, in the reaction:

$$N_{2(g)} + 2O_{2(g)} = 2NO_{2(g)}$$

an increase only in pressure would shift the equilibrium to the right because that would relieve the stress. On the left hand side of the equation there are three moles of gas and on the right hand side there are two moles of gas. Since all moles contain the same number of molecules (6.0×10^{23}) this means that there are fewer molecules present when the equilibrium is displaced toward the right. The pressure of a gas in a closed container is due to collisions between molecules and the wall of the container. If more molecules are present, the number of collisions will be greater and the pressure will be greater, so the equilibrium shifts to the right - toward fewer molecules - and there are less collisions.

An increase in pressure on the above system, at equilibrium, will produce a stress. This stress can be relieved when the equilibrium is displaced toward the side with fewer molecules because there will be less molecules to collide. Therefore, the above system would be displaced toward the right when the pressure is increased and the concentration of $NO_{2(g)}$ will increase while the concentrations of $N_{2(g)}$ and $O_{2(g)}$ decrease.

1. What is a closed chemical system?

2. Write a chemical equation and use it to describe chemical equilibrium.

3. A change in a closed chemical system produces a stress which is relieved by ____.

4. Explain why an increase in pressure on the system in equilibrium described by the equation $2H_{2(g)} + O_{2(g)} = 2H_2O_{(g)}$ will cause the equilibrium to shift and which way the shift will occur.

Answers

1. A closed chemical system is one where nothing is added or permitted to escape. This includes molecules and heat.

2. In the reaction $2Br_{2(g)} + F_{2(g)} = 2FBr_2$, at equilibrium the number of molecules of Br_2 combining with F_2 to form FBr_2 at any one time is equal to the number of molecules of FBr_2 splitting to give F_2 and Br_2 molecules.

3. A change in a closed chemical system produces a stress on the equilibrium which is relieved by a change in the concentrations of the reactants and the products.

4. The equilibrium shifts to the right because the stress on the equilibrium produced by an increase in pressure can be relieved by the combination of $H_{2(g)}$ molecules with $O_{2(g)}$ molecules to produce $H_2O_{(g)}$ which decreases the number of molecules. This smaller number of molecules has fewer collisions and this relieves the stress and the concentration of H_2O increases as the concentrations of H_2 and O_2 decrease.

Unit 8. Criterion Test

1. A change in a closed chemical system produces a stress which is relieved by ______________________________

2. The following system is at equilibrium:

$$2CO_{(g)} + O_{2(g)} = 2CO_{2(g)} + \text{Heat}$$

and the pressure is increased. Which way is the equilibrium shifted? Explain your answer.

3. The following system is at equilibrium:

$$2SO_{2(g)} + O_{2(g)} + \text{Heat} = 2SO_{3(g)}$$

and the pressure is increased, which way is the equilibrium shifted? Explain your answer.

4. The following system is at equilibrium:

$$\text{Heat} + CaCO_{3(s)} = CaO_{(s)} + CO_{2(g)}$$

and heat is added. Which way is the equilibrium shifted? Explain your answer.

5. The following system is in equilibrium:

$$\text{Heat} + 2HgO = 2Hg + O_{2(g)}$$

and heat is added. Which way is the equilibrium shifted? Explain your answer.

6. The following system is at equilibrium:

$$N_{2(g)} + 3H_{2(g)} = 2NH_{3(g)} + \text{Heat}$$

When heat is added and the pressure is increased what will happen to the equilibrium position? Explain your answer.

7. The following system is at equilibrium:

$$\text{Heat} + 2NO_{(g)} = 2NO_{2(g)}$$

When heat is added and the pressure is decreased what will happen to the equilibrium position? Explain your answer.